



CIVIL ENGINEERING

OPTIMIZATION TECHNIQUE

**INJECTION GROUT
OPTIMISATION**

REALIZED BY:

BARAOUZ ABDELFAH

SUPERVISED BY:

MISS. ELMKHALET MOUNA

SUMMARY

1- Cover page	01
2- Summary.....	02
3- Gratitude Word.....	03
4- Keywords.....	04
5-Introduction.....	05
- Motivation	
- Choice of the subject	
6-What is the injection technique ?.....	06
5.1- Definition and purpose of use of the technique	06
5.2-Injection procedure technique	07
7-Design and simulation of the area to be injected	08
8-Clarification of the problem.....	09
9-Mathematical approaches to solve the optimization problem...	11
- analytical study	
-Explanation of the method	
10-This project will be more effective if it will be carried out by a BE or by a large company	17
11-Perspective for a widening of this subject.....	17
12-Application in Morocco.....	18
13-Conclusion.....	18
14-References and library.....	19

gratitude Word

I would like to thank my dear professor :
EL MKHALET Mouna for increasing my knowledge in optimization techniques class and for their contribution to the project plan. Their support and their great availability allowed the completion of this work.

Keywords

- ***Grouting material***
- ***Optimization***
- ***Injection grout***
- ***Pressure***
- ***Algorithm-***
- ***Drilling***
- ***Statistical modeling***

INTRODUCTION

As part of the optimization technique course, we have been asked to do a research project that deals with an optimization topic in the field of civil engineering. In this way I decided to approach the optimization in the application of grouting and drilling points.

The motivation behind this project stems from the needs expressed by design engineers for specialized tools and technical methods to meet the requirements of grouting projects and their optimization (cost, time, efficiency and sustainability)

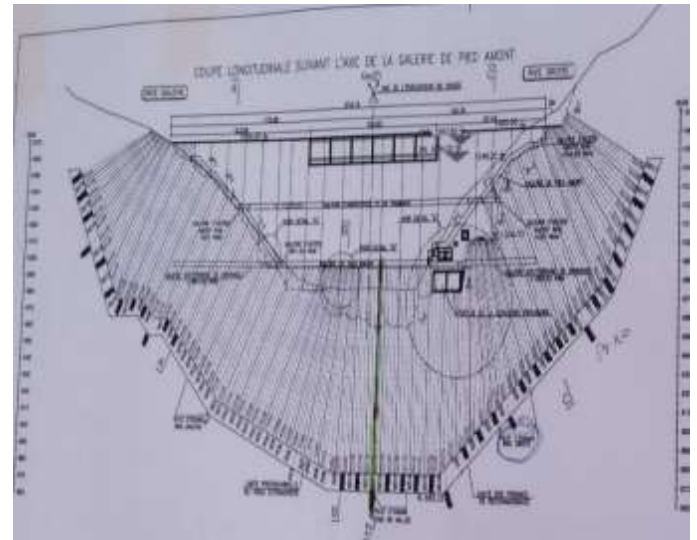
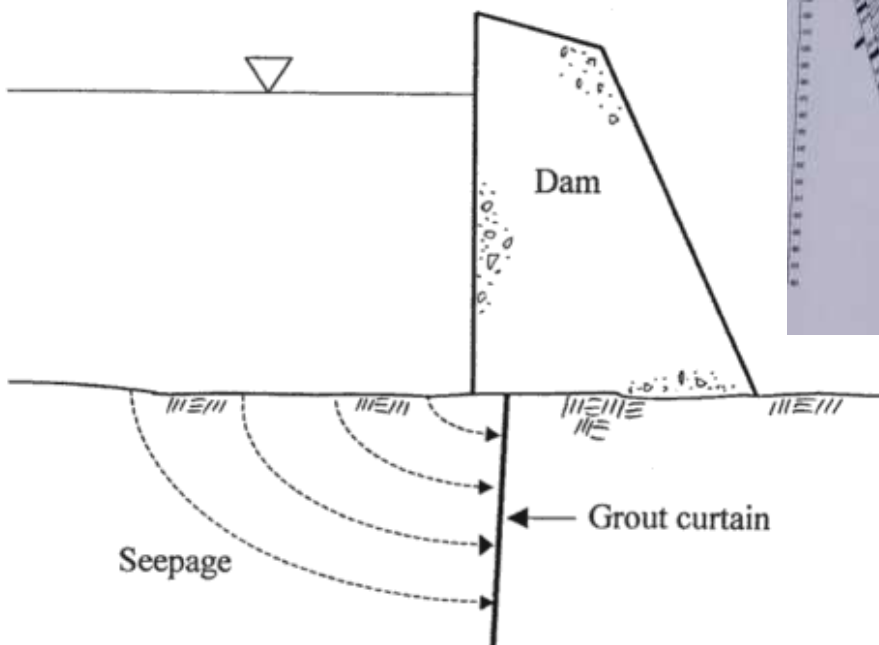
I chose this subject because during my initiation internship (Stage) that I carried out in a hydraulic dam the summer of 2020, I was interested and I had a lot of attention to the geotechnical studies, to the developments of basements, to the works of drilling, and to the techniques of injection of grout, with the aim of improving the basements and the waterproofness and the resistance of the rock massifs on which rest the foundations of the civil works, including the dams and other engineering structures.

what is grouting ?

5.1-Definition and purpose of use of the technique :

grouting is a technique -sometimes referred to as penetration grouting- ,it involves the filling of cracks,joints, or other generally smalldefects in rock , concrete , or masonry , or the pore spaces of soils, aggregates, or other porous media .The objective is to fill a void space without displacement of the formation or any change in the void configuration or volume.

This can be done for the purpose of strengthening the host formation, halting the flow of water through it , or a combination of the two .



Forming an impermeable curtain under dams is one of the users of grouting

5.2-Injection procedure technique :

5.2.1-materials :

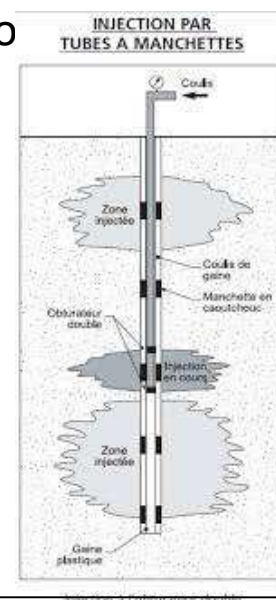
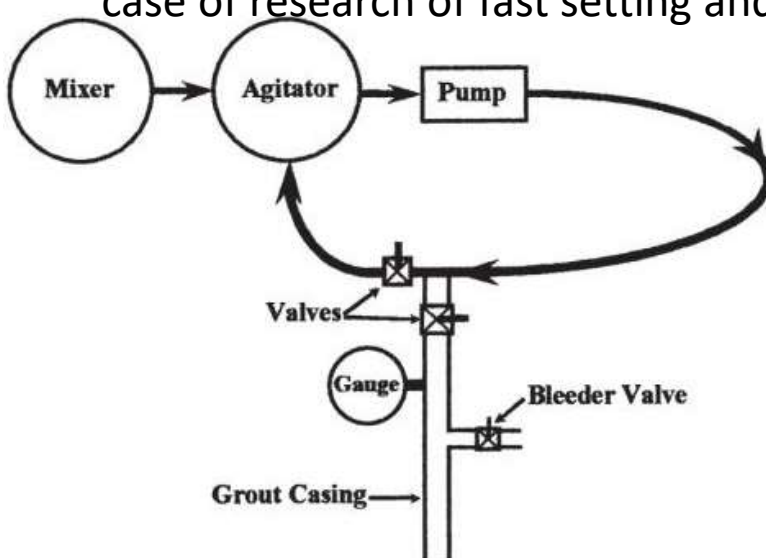
The grouting procedure requires a set of equipment, namely

- Agitator: The main use of the agitator is to store the grout that comes from the mixer until it is injected.
- Shutter: Designed for interventions and watertightness tests on all types of pipes
- Injection pump: Its purpose is to transmit the grout from the mixer to the place of installation
- Flowmeter : allows the calculation of the volume of grout injected
- Pressure gauge: for measuring the pressure
- Pressure sensor : allows to detect the grouting pressure

5.2.1-How it works:

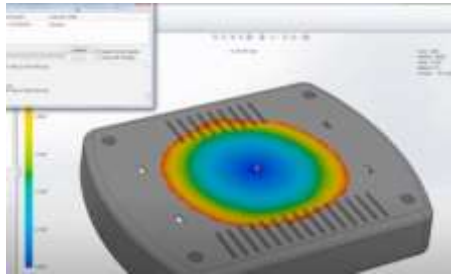
The injection is carried out from a mesh of boreholes equipped with cased tubes, cuffed tubes or cannulas, depending on the techniques required. These tubes or cannulas are placed in a cement grout sheath that prevents the grout from rising along the borehole. The grout is then injected under low pressure into the ground and penetrates the interstitial voids of the ground before it sets.

The grout is usually composed of water, cement and bentonite, sometimes with sand or fly ash. It can also be a chemical gel in case of research of fast setting and waterpro

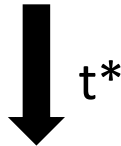


Design and simulation of the injection zone

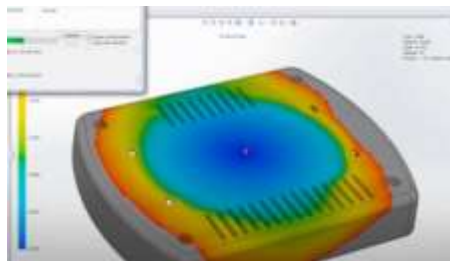
we assimilate this piece to the zone to be injected by the grout



the propagation of the grout in the zone at $t=t_0$

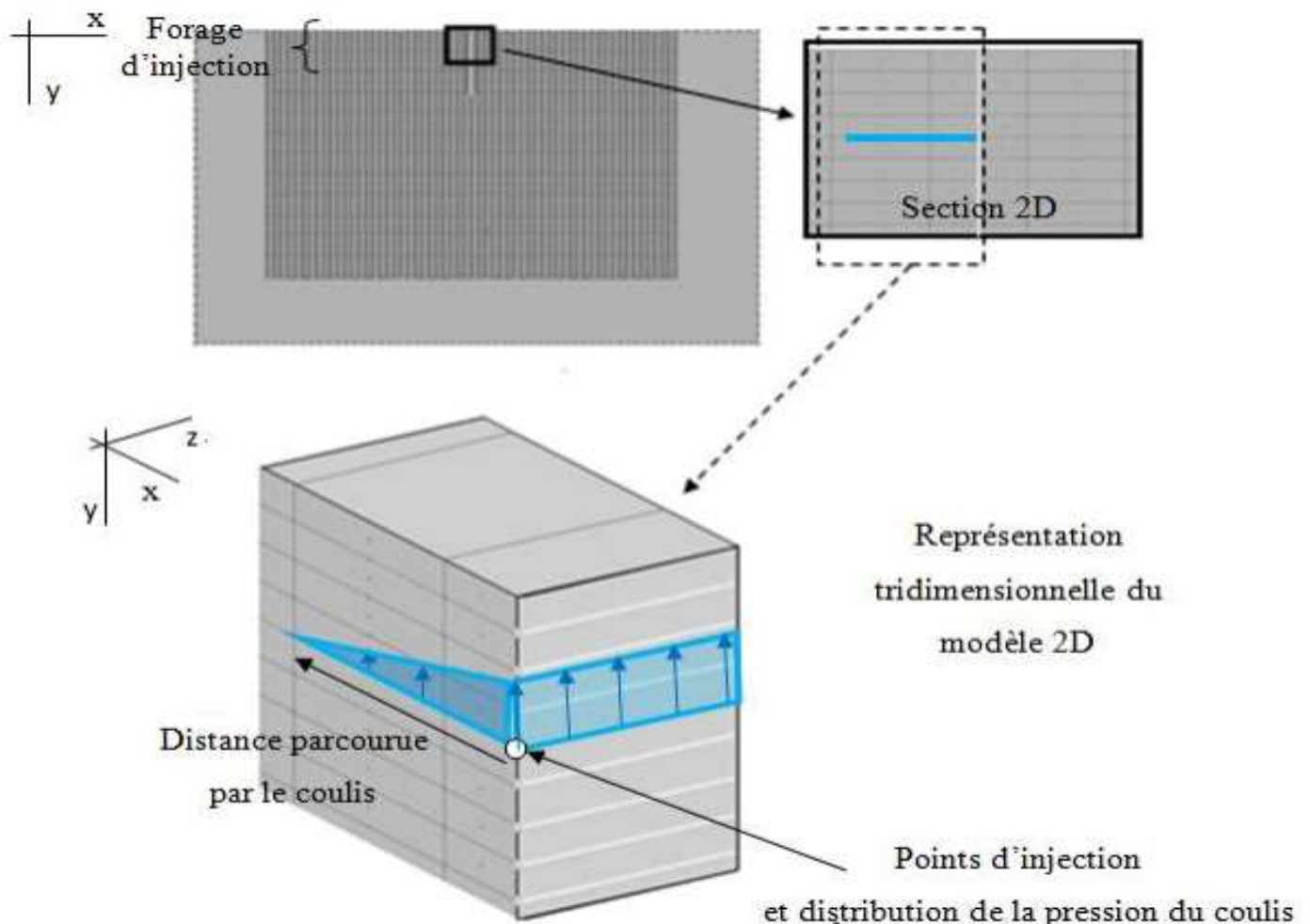


t^*



the propagation of the grout in the zone after a period of time $t=t_0+t^*$

a 3D view of the studied area shows how the grout is distributed in the subsoil layers



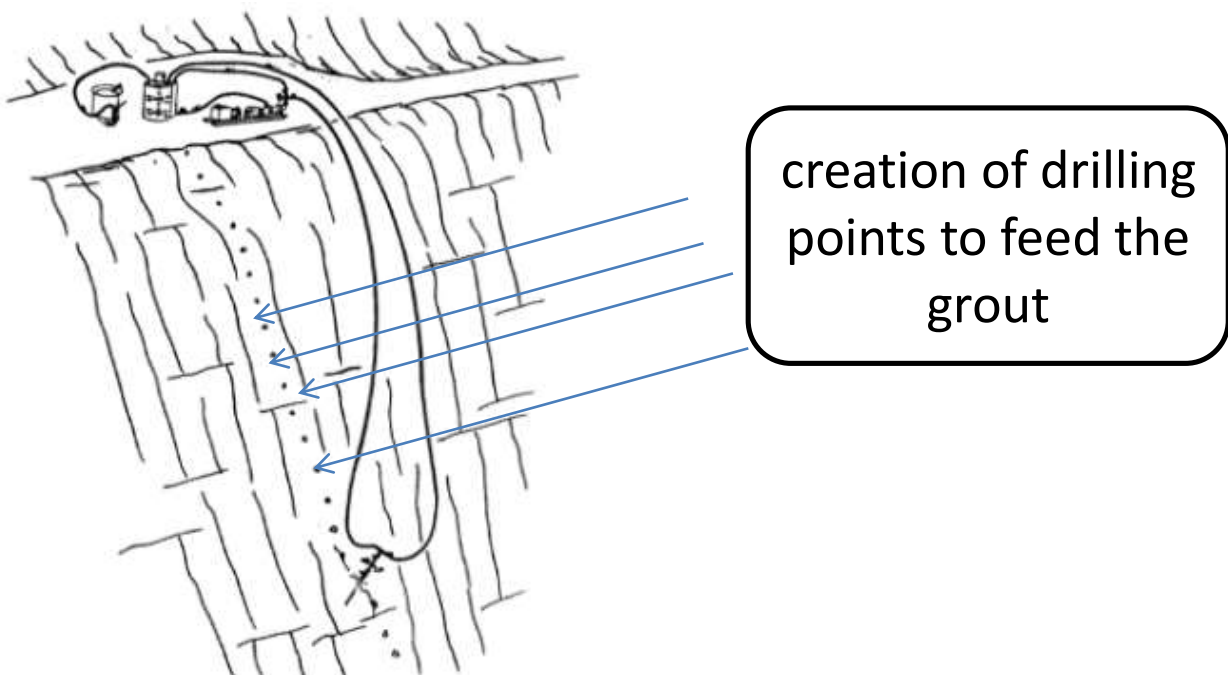
Clarification of the problem

Grouting is one of the complex issues that engineers may face when building structures and engineering works. Indeed, it is not possible to control the trajectory of the grout 100% within the soil layers, and the fact that the grout is affected by other factors such as temperature and pressure further complicates matters.

In addition, its properties can be damaged before reaching the right place.

Therefore, **time is a big challenge in such works.**

However, the idea of creating several points as sources to feed these joints to save time is not always a good idea because some structures cannot carry a specific number of these points as this may lead to their ruin.

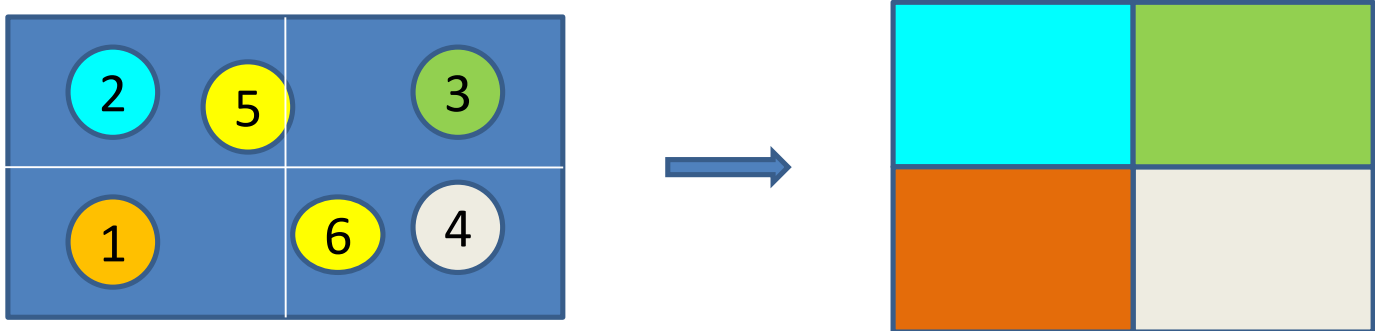


we are therefore faced with the problem of time, in other words: how to have an easy and brutal distribution of the grout. However, the large number of drilling points and holes to feed the grout can make destruction of the foundations and even if the structures .

For this reason we have to think about **two optimizations**:

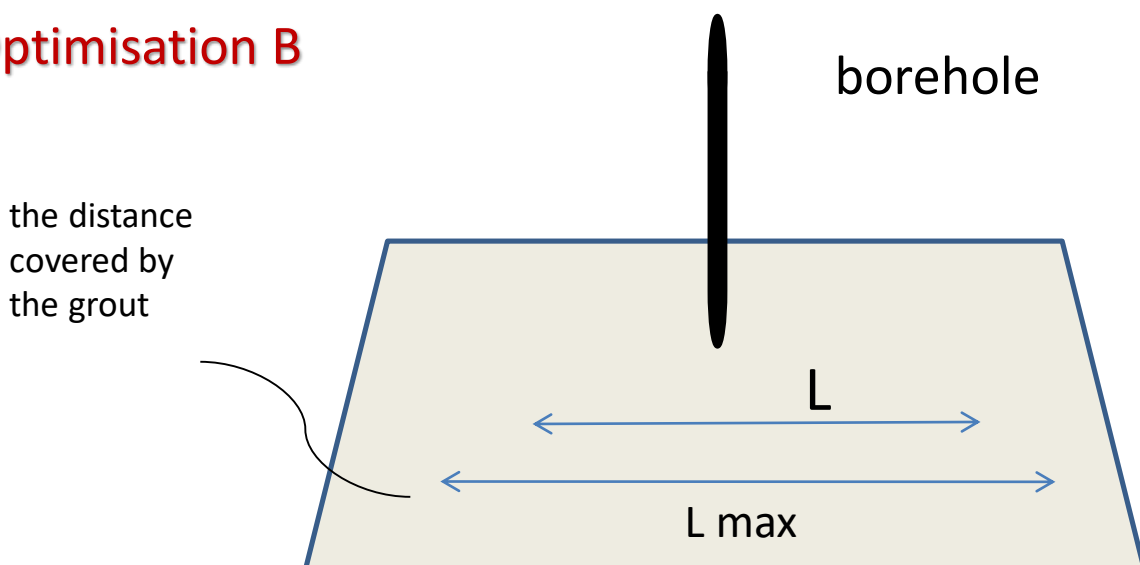
minimizing the number of grouting points : **Optimisation A**
maximizing the distance covered by the grout : **Optimisation B**

Optimisation A



c/c: we don't need to make the injection point 5 and 6 since 1 and 2 and 3 and 4 can supply the whole area.

Optimisation B

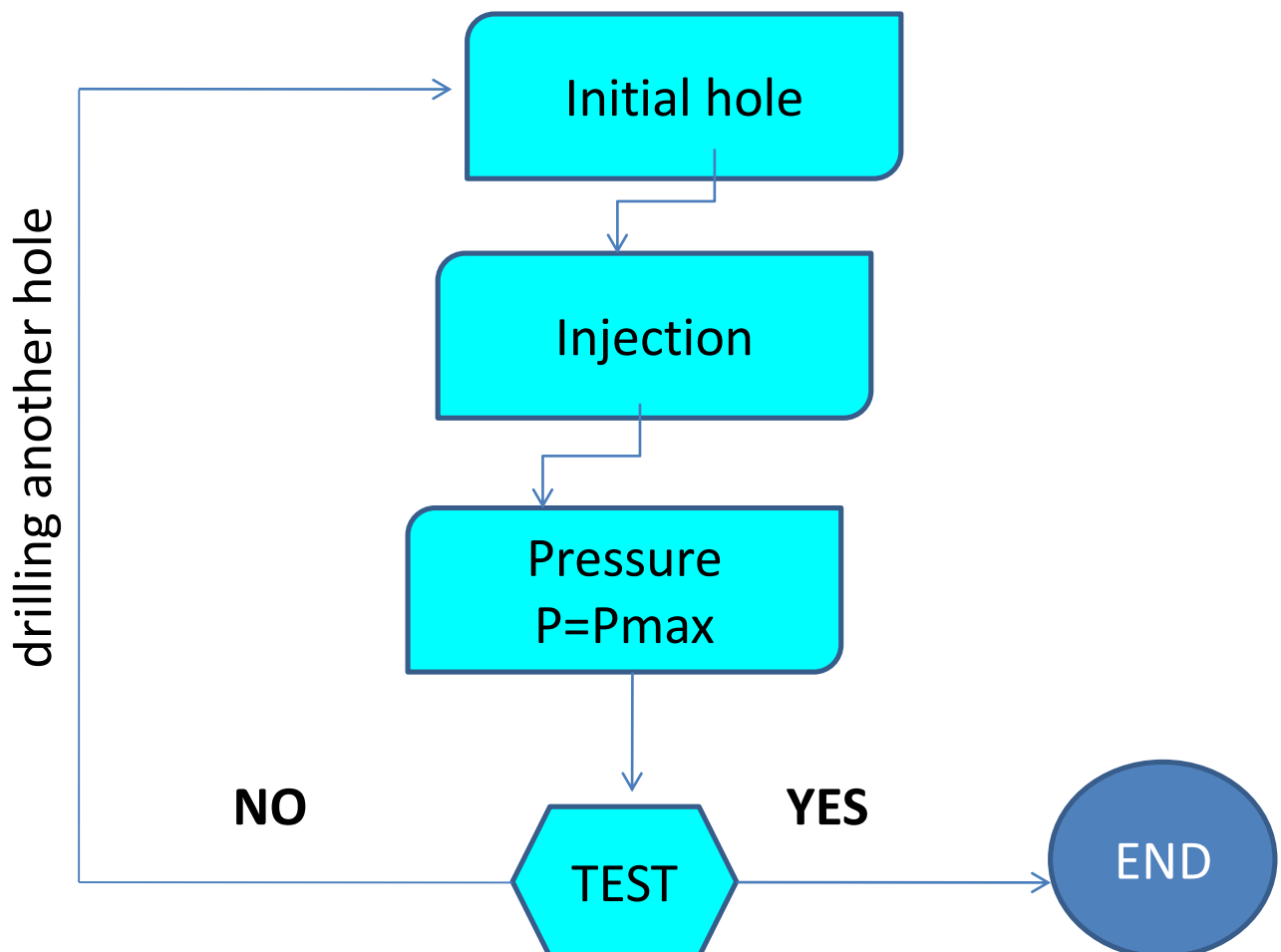


Mathematical approaches to solve the optimization problem

Introduction

Optimization plays an important role in operations research (a field at the frontier between computer science, mathematics and economics), in applied mathematics (fundamental for industry and engineering), in analysis and numerical analysis, in statistics for the estimation of the maximum likelihood of a distribution, for the search for strategies in the framework of game theory, or in control and command theory. Today, all systems that can be described by a mathematical model are optimized. The quality of the results and predictions depends on the relevance of the model, the efficiency of the algorithm and the means for numerical processing. In this section we will look to solve our optimization problem .

Principle of full optimization

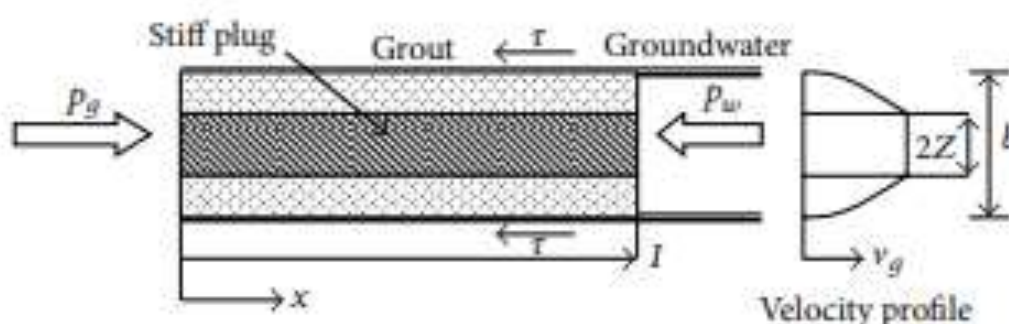


- **Pressure P**

The grouting pressure is chosen to ensure a good absorption rate, good penetration, to counteract the water pressure present in the fractures and not to create heave or fracturing. The criteria for the choice of grouting pressure are empirical and based mainly on experience and the thickness of the cover. The prescribed grouting pressure in North America is 1 psi per foot of cover, or approximately 25 kPa/m, regardless of the geomechanical conditions of the rock mass and the type of grout to be injected. This criterion remains conservative compared to the size of the vertical component due to the weight of the rock cover. In Europe, the grouting pressures are higher, i.e. 1 bar per meter of cover or 100 kPa/m. In Norway, the injection pressures are even higher, ranging from 500 to 1000 kPa per meter of canopy, due in part to the presence of good quality bedrock. In the literature, it is often discussed to optimize the grouting method by choosing a grouting pressure that favors the balance between good grout penetration without causing fracturing or plastic lifting. However, there are times when increasing grouting pressures to elastically open fractures is not necessary and other stopping criteria better meet the designer's objectives. In some cases, depending on the quality of the rock mass and the nature of the structure, it is possible to favour a flow of the grout rather than its diffusion under pressure. For example, the fact of grouting fractures for a nuclear cell or for the foundations of a dike does not involve the same environmental issues.

Grout Penetration

Let $I(t)$ be the position of the grout front at time t



A simple force balance of the difference between the grouting and the resisting water pressures, $\Delta p = p_g - p_w$, and the shear stress gives the maximum grout penetration, $I_{\max}$, for a fracture of aperture b :

$$I_{\max} = \Delta p \cdot b / 2\tau_0 \quad (*)$$

In order to obtain an analytical solution, the problem has to be simplified. In particular, it is assumed that the aperture is constant, not varying along the fracture. The grout properties are assumed to be constant in time

Derivation of Equations, Results, and Discussion

The velocity of grout, dI/dt , moving in a horizontal fracture of aperture b can according to Hassler be calculated as

$$dI/dt = - (dp/dx) \cdot (b^2/12\mu g) [1 - 3Z/b + 4(Z/b)^3]$$

Assuming parallel flow and a viscosity of the grout much higher than for water, the pressure gradient can be simplified to be

$$dp/dx = -\Delta p/l$$

Give $2Z/b = I/I_{\max}$. The equation for the relative penetration depth

$$I_D = I/I_{\max}$$

becomes from (*) after simplifications

$$dI_D/dt = (\tau_0)^2 / 6\mu g \Delta p \cdot (2 - 3I_D + (I_D)^3) / I_D$$

$$I_D = I/I_{\max} = 2Z/b .$$

We define the characteristic time t_0 and the dimensionless time t_D :

$$t_0 = 6\mu g \Delta p / (\tau_0)^2 \quad I_D = t / t_0$$

Gives the derivative dI_D/dt_D . The derivative of t_D as a function of I_D is :

$$dt_D / dI_D = I_D (2 - 3I_D + (I_D)^3) = I_D (2 + I_D) (1 - I_D)^2$$

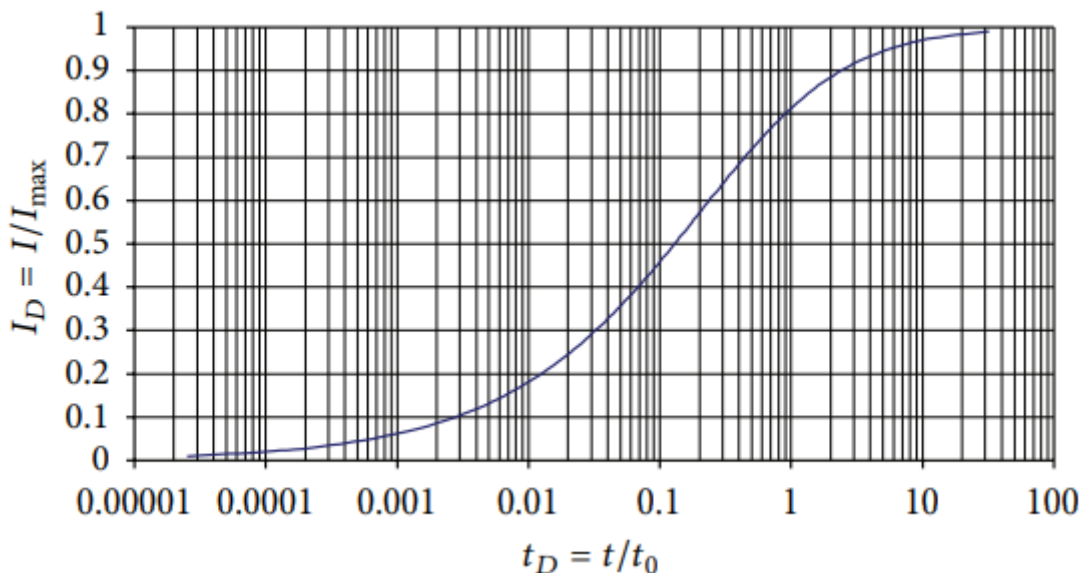
Right-hand function of I_D is the ratio between two polynomials, which may be expanded in partial fractions. These are readily integrated. We obtain the following explicit equation for the t_D as a function of I_D

$$t_D = F1(I_D) \quad F1(s) = s/3(1-s) + 2/9 \cdot \ln [2(1-s)/(2+s)]$$

it is straightforward to verify that derivative of last equation is given by second equation and that

$$I_D = 0 \text{ for } t_D = 0$$

A plot of $I_D = I/I_{\max}$ as a function of $t_D = t/(6\mu g \Delta p / (\tau_0)^2)$ is shown in next figure :



Some observations can be drawn:

- The relative penetration is not a function of the fracture aperture, b . This means that the penetration process has the same time scale for all fractures with different apertures penetrated by a borehole
- The time scale is only a function of the grouting pressure Δp , and the grout properties, μg and τ_0 . Thus the parameters are decided by choice of the grouter.
- The time scale is determined by $t_0 = (6\mu g \Delta p / (\tau_0)^2)$ so that at this grouting time about **80%** of the possible penetration length is reached in all fractures and after $5t_0$ about 95% is reached. After that the growth is very slow and the economy of continued injection could be put in doubt.

Experimental Verification

A series of grouting experiments were published by Hakansson, He used thin plastic pipes instead of a parallel slot for his experiments, and several constitutive grout flow models were tested against experimental data. As could be expected more complex models could give better fit to data, but the Bingham model gave adequate results especially in the light of its simplicity.

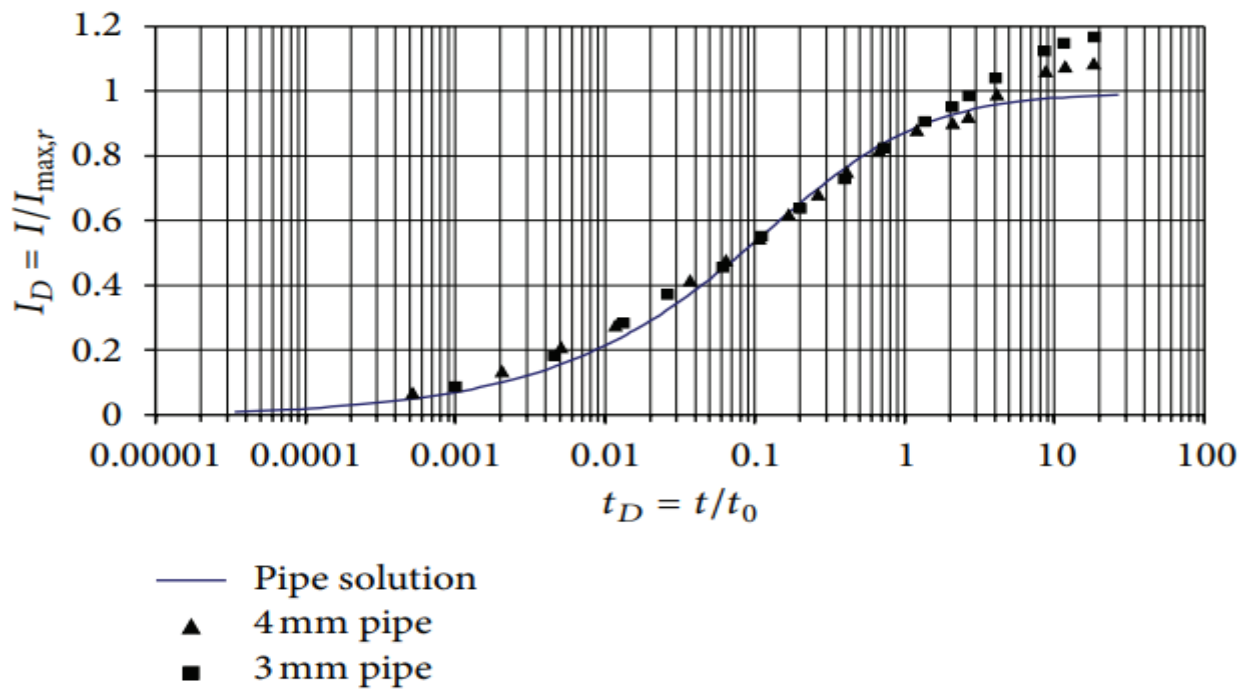
The velocity of grout moving in a pipe of radius r_0 can be calculated to be

$$\frac{dl}{dt} = -\frac{dp}{dx} \cdot \frac{(r_0)^2}{8\mu_g} \left[1 - \frac{4}{3} \cdot \frac{Z_p}{r_0} + \frac{1}{3} \cdot \left(\frac{Z_p}{r_0} \right)^4 \right]$$
$$Z_p = 2\tau_0 \cdot \left| \frac{dp}{dx} \right|^{-1}, \quad Z_p < r_0.$$

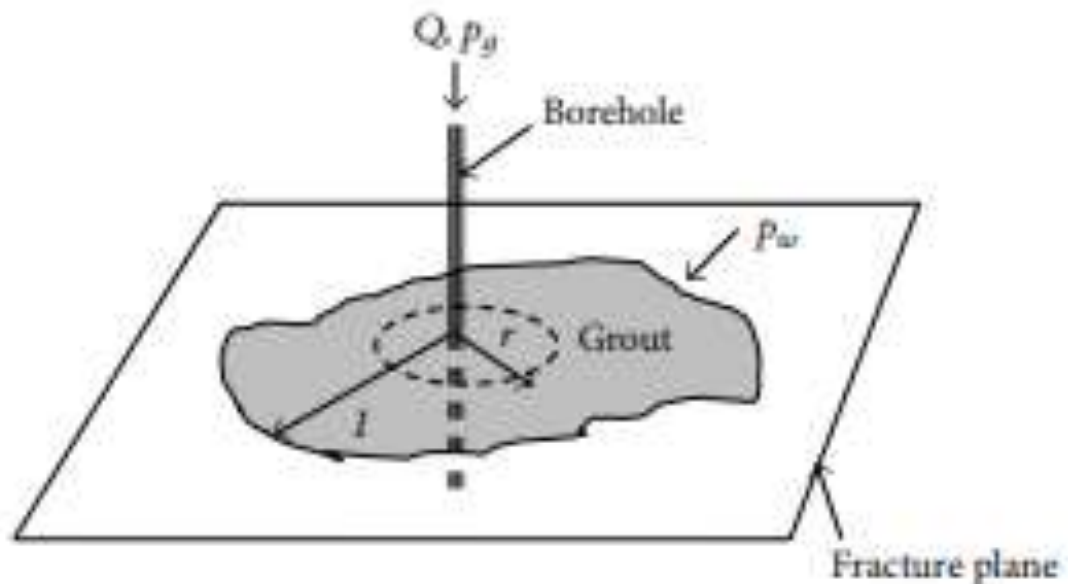
Here, Z_p is the radius of the plug flow in the pipe

Experiment	r_0 (m)	Δp (kPa)	τ_0 (Pa)	μ_g (Pa s)	$I_{max,p}$ (m)	t_0 (s)
3 mm	0.0015	50	6.75	0.292	5.55	1922
4 mm	0.002	50	6.75	0.292	7.40	1922

Comparison of grout penetration function in a pipe with experimental data from Hakansson



Radial penetration of grout in a fracture.



This project will be more effective if it will be carried out by a BE or by a large company

Structural engineering offices play an essential role: the company often needs their support from the project design stage. Thanks to their advice, the company will choose a suitable construction method to accurately size the elements.

In addition, the engineering and design departments also carry out soil studies before the work is carried out, comparing potential variants ... in order to determine the type of foundation adapted to a building site and to a project.

However, depending on the complexity of the project, the human resources of the company may have sufficient skills to design the project without the help of a design office. It will judge itself of the need or not to call upon a specialist.

But in my opinion, I think that it was necessary to entrust this type of project to the design offices because they are complex projects and require specialists.

But in fact, the large company that works with a design office can benefit from the know-how of the engineering teams.

Perspective for a widening of this subject

This subject is a bit complicated, because it is intertwined in several fields, and wherever there is complexity, there is the possibility of expansion, development and enlargement in order to search for easier and more optimized solutions. It is possible to develop plaster materials and innovate new drilling techniques without threatening the structure, as well as innovative methods of plaster injection . Or else model the principles in this project with stronger software and models

Application in Morocco

This technique is considered one of the ancient techniques and is still applied today,

In Morocco, many construction projects in civil engineering have adopted these techniques, including the construction of dams, but the level of improvement and optimization actually varies according to the techniques and models adopted.

Conclusion

In conclusion, the results and the analysis related to the phenomenon of lifting and the optimization of the injection operations, with a one-dimensional model and the two-dimensional give an interesting track, but the three-dimensional character of the phenomenon of injection makes it difficult to directly compare the lifting pressures to those observed in reality.

References and library

- **Google Scholar , Youtube**
- U. Hakansson, ° Rheology of fresh cement-based grouts [thesis], Department of Soil and Rock Mechanics, KTH, Stockholm, Sweden, 1993. [11] G. Gustafson and
- Hassler, ° Grouting of rock—simulation and classification [thesis], Department of Soil and Rock Mechanics, KTH, Stockholm, Sweden, 1991.
- **Construction and Design of Cement Grouting: A Guide to Grouting in Rock**
- [Practical Handbook of Grouting: Soil, Rock, and Structures - James Warner - کتب Google](#)
- [Optimization and application of backfill grouting material for submarine tunnel – ScienceDirect](#)
- J.H. Mao **Study on the Grouts Diffusion Mechanism of Shield Tunnel Back-filled Grouts Based on Filtration M.Sc. Thesis**
- Gallagher, S. (2012). Mechanical resistance of cracked dam mass concrete repaired by grouting : an experimental study (Dissertation/Thesis, École Polytechnique, Montréal, Québec). (MR94981). Tiré de <http://publications.polymtl.ca/1013/>
http://gateway.proquest.com/openurl?url_ver=Z39.88-2004&rft_val_fmt=info:ofi/fmt:kev:mtx:dissertation&res_dat=xri:pqdiss&rft_dat=xri:pqdiss:MR94981